Feeder cable sizes range from 100 to 4200 pair cable for copper, and from 12 to 216 strands for fiber. Multiple cables are installed along feeder routes when the maximum size of a single cable is exceeded. Main feeder routes taper as they pass the splice points at which subfeeder branches off to connect to the individual serving areas. Thus, the main feeder cable sizes generally decrease in increments as the distance from the wire center increases.

Both copper and fiber feeder cable may appear on a single main feeder route to provide connections to different serving areas. If they do, they share most structure, including poles, manholes and trenching. Copper and fiber cables are assumed not, however, to share conduit when they do follow the same route.

6.4.2. Development of Feeder Investments

6.4.2.1. Calculating Main Feeder and Subfeeder Distances

As was shown in Figure 6, main feeder routes extend from the wire center in as many as four directions.[55] Subfeeder cables branch from the main feeder at right angles, giving rise to the familiar tree topology of feeder routes. The points at which subfeeders branch off the main feeder delineate main feeder segments, which are the portions of main feeder cable between two branch points.[56]

The centers (centroids) of the main clusters may fall in any of the four feeder route quadrants. As shown in Figure 7, a set of parameters, including the quadrant, airline (radial) distance and angles (omega and alpha), locate the main cluster with respect to the serving wire center. With this information, HM 5.0a applies straightforward trigonometric calculations to compute main feeder and subfeeder distances.[57] The model computes sufficient subfeeder cable to connect the main feeder route to the centroid of each main cluster. Copper feeder cable always terminates at an SAI at the centroid of the main cluster. If the model calls for fiber feeder, the subfeeder terminates at an RT at the centroid, adjacent to an SAI.

[55] If no cluster centroids fall within a given quadrant of a wire center, no feeder route will be provided in that quadrant.

[56] Splicing is required where the main feeder branches into subfeeder. The cost of splicing, including material, equipment, and labor, is included with the cost of the cable assumed in the model.

[57] In rural areas where a feeder route may serve only one or two main clusters, this rectilinear routing assumption is extremely conservative relative to the efficiencies that could be realized using a steered feeder routing.

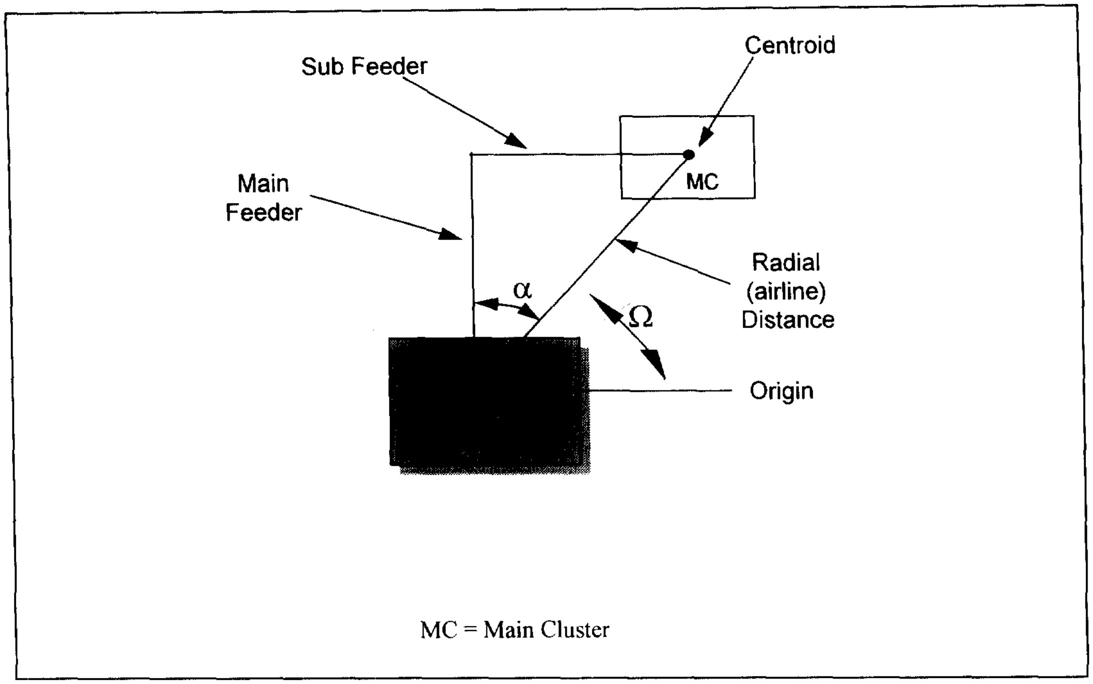

Figure 7 Determination of Cluster Locations and Distances

The criteria by which the Model decides if a main cluster is served by copper or fiber feeder cable have been discussed in the Distribution Module description, since this decision is made there.

Figure 8 demonstrates that multiple serving areas share capacity on certain segments of the main feeder route. Segments located closer to the wire center require more capacity than segments near the periphery. HM 5.0a addresses this need by tapering the main feeder facilities as the distance from the wire center increases. Thus, it must determine the various "segment distances," shown as S-1, S-2, ..., in Figure 8, so it can size the cable in each segment. The segment distances along a main route are calculated in two steps. First, the main clusters are sorted so they appear in the order of increasing distance along the main route. Segment distances are then calculated as the difference between the main feeder distances of adjacent main clusters.

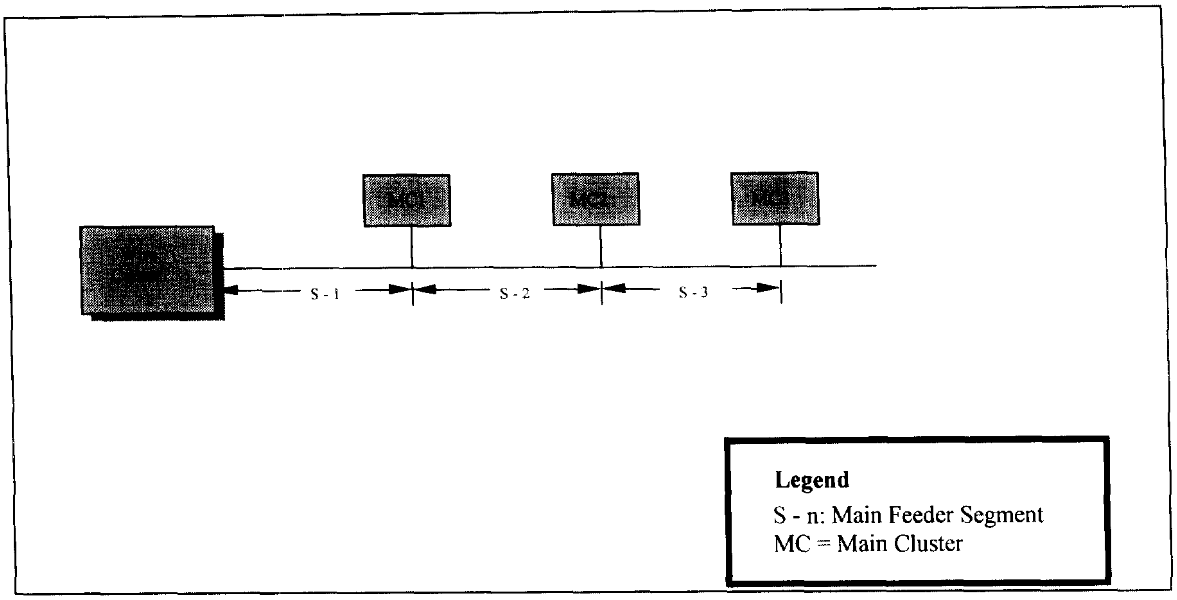

Figure 8 Main Feeder Segmentation

6.4.2.2. Copper and Fiber Subfeeder Cable Sizing

Sizing copper subfeeder cable for individual serving areas is a function of two parameters: the total number of lines within the serving area and the copper feeder sizing factor. To select the appropriate cable size, the required line capacity is computed by dividing the total number of lines in the serving area by the sizing factor. The model then chooses the smallest cable size that meets or exceeds this quotient. For instance, if the number of lines is 200 and the sizing factor is 0.80, the next cable size larger than 200/0.80 is selected. Since 200/0.80 equals 250, the 400 pair cable is selected. As with distribution cable, this may lower substantially the average effective fill compared to the input value entered. Multiple cables are used in cases where the maximum cable size is surpassed.

The number of optical fibers needed to serve a given serving area is calculated by multiplying the number of DLC RTs in that serving area by the number of strands per RT. The strands per RT is a user-adjustable quantity, with a default value of four.[58] In the subfeeder to a particular serving area, the model chooses the smallest optical fiber cable size that meets or exceeds the required number of strands, with a minimum cable size of twelve fiber strands. In the main feeder, the fiber cable on each segment is sized to meet the aggregate demand of serving areas beyond that segment, taking a user-adjustable fiber strand fill factor into account.

6.4.2.3. Main Feeder Segment Sizing

[58] Because a DLC terminal requires a minimum of two fibers, one for each direction of transmission, the HM 5.0a default of four fibers provides complete redundancy.

Each segment in the main feeder is sized to meet the requirements of all the serving areas located past the segment. For example, in Figure 8, segment 1 is sized with adequate capacity for serving areas 1, 2, and 3. Segment 3 will be sized with less capacity than segment 1 since it serves only serving area 3. Thus, the individual cable requirements for serving areas at and beyond the end of a particular main feeder segment are aggregated to determine the required cable size for that main feeder segment. When the maximum cable size is exceeded on a given segment, multiple cables are installed.

6.4.2.4. Structure Investments

The fraction of aerial, buried and underground plant may be set separately for all density ranges and for each feeder cable type, copper or optical fiber. Based on these fractions, the distances involved, and the cost of various structure components, the Feeder Module calculates the investment in feeder structure.

In addition to the sharing of structure between telephone companies and other utilities, there are two other forms of structure sharing relevant to feeder plant. First, with the exception of conduit, structure is shared between copper and fiber feeder cables along main feeder routes. Second, structure is shared between feeder and interoffice facilities. A detailed discussion of the latter type of sharing is presented in the interoffice section of this document.

6.4.2.5. Allocation of Main Feeder Investments

All the feeder facility investments are computed on a per-serving area basis. To do this, it is necessary to assign the appropriate amount of investment in each segment of the main feeder route to the individual serving areas that are served by that segment. The portion of a main feeder segment investment assigned to a serving area whose lines are carried on that segment is computed using the ratio of lines in that serving area to total number of lines in all serving areas carried on that main feeder segment. This is done separately for the copper and fiber feeder that may coexist on a given route.

6.4.2.6. Relevant Input Parameters

The set of user inputs and default values used in feeder calculations appear as inputs B46-B57 and B70-B71, described in Appendix B. The Feeder Module also calculates terrain impacts using inputs B20-B23. It allows the user to enable feeder steering and to set the route/air ratio using B26 and B27, respectively; can override the calculated aspect ratio of the main cluster and thereby force main clusters to be square using B27a; and specifies excavation and restoration costs (jointly with distribution) using B197 through B201.

6.5. Switching and Interoffice Module

6.5.1. Overview

This Module produces network investment estimates in the following categories:

a) *Switching and wire center investment* -- This category includes investment in local and tandem switches, along with associated investments in wire center facilities, including buildings, land, power systems and distributing frames.

b) *Signaling network investment* -- This includes investment in STPs, SCPs and signaling links.

c) *Transport investment* -- This category consists of investment in transmission systems supporting local interoffice (common and direct) trunks, intraLATA toll trunks (common and direct) and access trunks (common and dedicated).

d) *Operator Systems investment* -- This includes investments in operator systems positions and operator tandems.

6.5.2. Description of Inputs and Assumptions

For the Switching and Interoffice Module to compute required switching and transmission investments, it requires as inputs total line counts for each wire center, distances between switches, and traffic peakedness assumptions, as well as inputs describing the distribution of total traffic among local intraoffice, local interoffice, intraLATA toll, interexchange access and operator services. This module takes as data inputs minutes and calling volumes from ARMIS, overall line counts obtained from the PNR database for the serving areas belonging to that wire center, and wire center locations and interoffice distances from the distance file for the calculation of transmission facilities investments.[59] It also requires many user-adjustable input assumptions. The set of user inputs and default values described in Appendix B and used in various phases of the module include:

- B74-B85 and B176-B177, for end office switching;
- B86-B91, for the wire center in which the end office switches and tandems are housed.
- B107-B130, for interoffice transmission terminals, media and structures;
- B143-B149, for tandem switching;
- B150-B163, for interoffice signaling; and
- B164-B167, for operator services and public telephone.

In addition, various traffic parameters are provided by inputs B92-B106, and miscellaneous parameters, such as the percent of traffic that requires operator assistance, percent that is interoffice, and percent that is routed directly between end offices, are provided by B131-B142. Finally, there is a set of inputs representing surrogate per-line investment in various switching and signaling equipment components by small

[59] HM 5.0a includes a set of interoffice distance calculations produced from wire center location information from Bellcore's Local Exchange Routing Guide (LERG) and from NECA Tariff 4.

independent telephone companies ("ICOs"), appearing as B168-B175. These are used in lieu of the results that would be calculated by the model for small ICOs with less than fifty wire centers, and better reflect these ICOs' typical practice of purchasing usage of such components from larger LECs.

Many of the calculations in the Switching and Interoffice module rely on traffic assumptions suggested in Bellcore documents.[60] These inputs, which the user may alter, assume 1.3 busy hour call attempts ("BHCA") per residential line and 3.5 BHCA per business line. Total busy hour usage is then determined based on published Dial Equipment Minutes ("DEM") information. Other inputs, which may be changed by the user, specify the fraction of traffic that is interoffice, the fraction of traffic that flows to operator services, the local fraction of overall traffic, as well as breakouts between direct-routed and tandem-routed local, intraLATA toll, and access traffic.

6.5.3. Explanation of Calculations

The following sections describe the calculations used to generate investments associated with switching, wire centers, interoffice transport, signaling and operator systems functions.

6.5.3.1. End Office Switching Investments

The Module places at least one end office switch in each wire center. It sizes the switches placed in the wire center by adding up all the switched lines in the CBGs served by the wire center, applying a user-adjustable administrative line fill factor, and then comparing the resulting line total to the maximum allowable switch line size. The maximum switch line size parameter is user-adjustable; its default setting is 80,000 lines plus trunks. The model will equip the wire center with a single switch if the number of ports (lines and trunks) served by the wire center is no greater than a user-adjustable maximum size – that defaults to 80,000. If a wire center must serve, say, 90,000 ports, the model will compute the investment required for two 45,000-port switches.[61]

The wire center module performs two additional capacity checks. First, it compares the BHCA produced by the mix of lines served by each switch with a user-adjustable processor capacity (default set at a maximum of up to 600,000 BHCA, depending on the size of the switch) to determine whether the switch is line-limited or processor real-time-limited. In making this calculation, the per-line BHCA input is multiplied by a user-adjustable processor feature loading multiplier. The default value of the feature loading

[60] Bell Communications Research, *LATA Switching Systems Generic Requirements, Section 17: Traffic Capacity and Environment*, TR-TSY-000517, Issue 3, March 1989.

[61] If multiple switches are required in the wire center, they are sized equally to allow for maximum growth on each switch.

multiplier varies between 1.2 and 2.0, depending on business line penetration,[62] to reflect additional processing loads caused by features.

Second, the module compares the offered traffic, expressed as BHCCS, with a user-adjustable traffic capacity limit (default set at a maximum of up to 1,800,000 BHCCS, depending on the size of the switch). To make this comparison, the per-line traffic estimate calculated from the reported DEMs is multiplied by a user-adjustable holding time multiplier, which can be separately set for business and residence customers. Default values of the business and residential holding time multipliers are 1. They can be increased above that value to reflect the incidence of calls that have longer than normal holding times, and thus increase the traffic load on the switch. A example could be heavy Internet access via the voice network. If either of these processor or traffic capacity tests leads to the corresponding limit being exceeded, the model will compute the investment required for additional switches, each serving an equal number of total lines.

HM 5.0a is capable of engineering and costing end office switching systems comprised of explicit combinations of host, remote and standalone switches. But, because accurate data on the purchase prices of a portfolio of host, remote and standalone switches of varying capacities may not be available to the user, the HM 5.0a Switching and Interoffice Module defaults to computing end office switching investments using input values that average per-line investments over an efficient portfolio of host, remote, and standalone end office switches. Thus, the model's calculated end office switching investments and corresponding costs subsume either explicitly specified switch technologies on a wire center by wire center basis, or a blended overall efficient mixture of host, remote, and standalone switches within the modeled network.

If the user selects the explicit host, remote, standalone option, the user must specify for each wire center whether the housed switches are hosts or remotes, as well as assign correspondences between hosts and remotes. The model will designate all remaining wire centers as housing standalone switches. The model then places the hosts and their subtending remotes on SONET rings separate from the interoffice rings discussed below. Host switches may therefore appear on two rings -- their local host/remote ring, and (if the host directly serves more than the user-specified small office line limit) a larger interoffice ring interconnecting end offices and tandem locations.

The model sizes the host-remote rings to accommodate host-remote umbilical trunk and control link requirements. It then computes investment in SONET add/drop multiplexers ("ADMs") and digital cross connects ("DCSs") for the host/remote ring and calculates the average ADM and DCS investment per line for all lines in the system. The host interoffice calculations also are adjusted to account for the increased trunk and signaling capacity requirements imposed by the remotes served by the host.

[62] The multiplier is set at 1.2 up to a business penetration (i.e., % business lines) threshold set by the user, then increases linearly to 2.0 at 100% business penetration.

End office switching investment calculations obtain common equipment and per-line investments for all three switch types from a user-adjustable investment table, which contains end office investment entries for both large and small LECs. Once the model computes investments for each switch in a host/remote system, it calculates the average investment per line for all of the lines in the system.

In more detail, the costing process is as follows. When the host-remote option is selected, switching curves that correspond to host, remote and standalone switches are used to determine the appropriate switching investment. These new switching curves incorporate a fixed plus variable investment per line for each switch type. It is recognized that there are large and small host and standalone switch technologies, and that remotes are available in multiple line sizes. Remote switches cause incremental variable investments primarily associated with the umbilical trunk ports necessary to carry traffic originating and terminating on the remote lines to the host switch. The user adjustable fixed and variable investments for host, standalone and remote switches have been scaled accordingly. In accordance with the FCC's Public Notice guidelines, the cost of an entire switching system consisting of a host and its associated remotes, is allocated evenly over all lines served by the host-remote configuration.

In default mode, the model assumes a blended configuration of switch technologies. The switching cost curves for this blended configuration were developed using typical per-line prices paid by BOCs, GTE and other independents as reported in the Northern Business Information ("NBI") publication, "U.S. Central Office Equipment Market: 1995 Database."[63] In addition, public line and switch data from the ARMIS 43-07 and responses to the USF NOI data request from 1994 are also employed.

The module uses a large telephone company switching investment curve that is based on the RBOC and GTE average switching costs per line reported in the NBI study. These two switching cost points were paired with the average sizes of current RBOC and GTE switches derived from 1995 ARMIS 43-07 line and switch data. A third cost point for large switches of 80,000 ports was developed from other industry sources. A logarithmic curve was then fit to these data using least-squares regression. As demonstrated in Figure 9, this functional form fits the data very closely.

The 1993 USF NOI (Universal Service Fund Notice of Inquiry) data was used to estimate an average line size for small LEC switches. A 1995 average line size was estimated by assuming the ICOs have experienced growth in average lines per switch between 1993 and 1995 similar to that experienced by GTE. The value on the large LEC curve corresponding to this 1995 small LEC average line size was compared to the ICO per line value from the NBI report. This produced a 1.7 factor which was applied to the constant term in the logarithmic functional form to produce a curve of identical shape, but shifted upward by $173 per line compared to the large LEC curve. The "slope" multiplier

[63] Northern Business Information study: U.S. Central Office Equipment Market -- 1995, McGraw-Hill, New York , 1996

(default of -14.922 in Figure 9) and the constant term (default of 242.73 in Figure 9 for large LECs and default of 416.11 for small ICOs) are user adjustable.

The per-line investment figures from the NBI study are for the entire end office switch, including trunk ports. The investment figures are then reduced by $16 per line to remove trunk port investment based on NBI's implicit line to trunk ratio of 6:1. The actual number of trunks per wire center is calculated in the transport calculation, and the port investments for these trunks are then added back into the switching investments. Figure 9 shows the switching investment curves for large LECs resulting from this methodology.

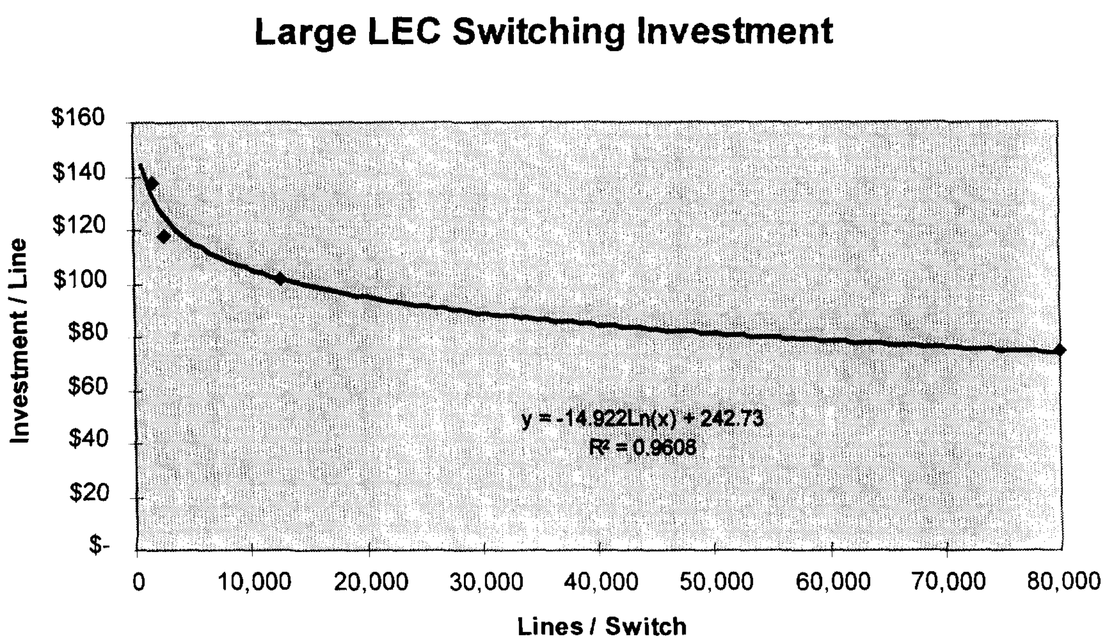

Figure 9 **Blended Switch Investment Curve**

Wire center investments required to support end office and tandem switches are based on assumptions regarding the room size required to house a switch (for end offices, this size varies according to the line sizes of the switch), construction costs, lot sizes, land acquisition costs and investment in power systems and distributing frames.

The model computes required wire center investments separately for each switch. For wire centers housing multiple end office switches, the wire center investment calculation adds switch rooms to house each additional switch.

6.5.3.2. Transport Investments

The traffic and routing inputs listed previously, along with the total mix of access lines served by each switch, form the basis for the model's transport calculations. The model determines the overall breakdown of traffic per subscriber according to the given traffic assumptions and computes the numbers of trunks required to carry this traffic. These calculations are based on the fractions of total traffic assumed for interoffice, local direct routing, local tandem routing, intraLATA direct and tandem routing, and access dedicated and tandem routing. These traffic fractions are applied to the total traffic generated in each wire center according to the mix of business and residential lines and appropriate per-line offered load assumptions. The model computes the total offered load per wire center for various classes of trunks – e.g., local direct-routed trunks. It then compares the offered load for a trunk class to a traffic engineering threshold. If the offered load exceeds the threshold, the computed number of trunks is just the quotient of the total offered load divided by the user-specified maximum trunk occupancy (default = 27.5 CCS). If the traffic load is less than the threshold, the model obtains the correct number of trunks using Erlang B assumptions and 1% blocking from a lookup table.

The traffic engineering threshold value is determined from the user-specified maximum occupancy value through another table lookup which determines the number of trunks that will carry the specified maximum occupancy at 1% blocking. The threshold value is the product of the input maximum occupancy and the corresponding number of trunks. The user may enter maximum occupancies between 17.5 and 30 CCS.

HM 5.0a assumes that, with some exceptions, all interoffice facilities take the form of a set of interconnected Synchronous Optical Network (SONET) fiber rings. It uses a program written in Visual Basic for Applications (VBA) and the wire center locations specified as V&H coordinates to compute a set of rings comprising the interoffice network. These ring calculations apply to all operating companies that have at least one tandem.

The interoffice network of rings consists of two ring classes: host/remote and tandem/host/standalone. If the user invokes the feature that allows hosts and remotes to be specified, host/remote rings are used to interconnect remote switches to their serving host. Tandem/host/standalone rings interconnect hosts and standalone wire centers to their serving tandem. The methodology that the Model uses to determine the rings is the same for both classes of rings, with hosts serving as the homing point in the network of hosts, remotes and tandems serving as the homing point in the network of tandems, hosts, and standalone wire centers. Any discussion in the following section is applicable to both the host/remote and tandem/host/standalone classes, unless otherwise noted.

The interoffice distance calculations in HM 5.0a are considerably more sophisticated than earlier versions of the Hatfield/HAI Model.[64] To compute the set of interoffice rings, the HM begins with a case where all wire centers are directly connected to their serving tandem via redundant paths. Each wire center is then examined to determine whether it is more advantageous to leave the wire center directly connected to the tandem or incorporate it into a ring. To make this determination, the HM compares the investment associated with directly connecting the wire center to the tandem with the investment

[64] See Appendix D for a fuller description of these calculations.

associated with placing the wire center on a ring. For direct connections, the investment is a function of the distance from the wire center to the tandem. When determining the investment that is required to add a wire center to a ring, the distance between interconnected wire centers and the additional cost of multiplexing are considered. If the investment on the ring is less than the investment associated with directly connecting to the tandem, the office will be placed on the ring.

The HM 5.0a incorporates an optimizing algorithm to ensure that it constructs rings in an efficient fashion. The savings that are generated by placing a wire center on a ring are computed as the difference between on-ring and directly connected investment. The HM places the offices that produce the greatest savings on the ring first. When no more savings are possible, the process of creating rings is complete.

When computing rings, the greatest savings often is realized by allowing a set of wire centers to form their own standalone ring that does not include the serving tandem as a node. The algorithm requires the tandem to be placed on at least one ring. But since all wire centers must have a communications path to their serving tandem, standalone rings are connected to the tandem through a series of ring connectors that provide paths either between rings, or between a standalone ring and the tandem. The location of each ring connector is determined by identifying the smallest distance from each node on the standalone ring to either the tandem itself, or to any other ring that has tandem connectivity. All ring connector distances and connector terminal costs are doubled to reflect the installation of redundant facilities.

Since rings are interconnected, traffic between wire centers on two rings may "transit" one or more additional rings. Thus, the calculated capacity of a ring, based on the traffic originating/terminating in wire centers on the ring, must be increased to reflect the requirement that the ring also be able to handle transiting traffic. The actual amount of such transiting traffic on a ring is highly dependent on (1) the position of that ring in the overall configuration of rings serving a given area; and (2) the amount of traffic generated (or terminated) by wire centers on a given ring that is destined for wire centers on another ring, and therefore "leaks" out of the originating ring. The model increases the capacity of each ring to handle transiting traffic based on a user-adjustable "transiting factor," whose default value is 0.4. This factor represents the percentage of additional ring capacity consumed by transiting traffic. Thus; the model increases the calculated ring capacity requirement by (1 + transiting factor).

There are two user-adjustable parameters that govern the creation of rings. First, it is possible to set the maximum number of wire centers that may share the same ring – see parameter B142 in Appendix B. The default number is 16. Once this limit has been reached, no additional wire centers will be absorbed by the maximally sized ring – even if doing so would produce a network with a smaller total investment. The second, which applies only to host/standalone/tandem rings, is a threshold value dictating the minimum number of switched plus special lines a wire center must serve to be eligible to be placed on a ring. This threshold corresponds to Parameter B139 in Appendix B; its default value is one.

Wire centers that serve fewer than this threshold total line count will either: 1) directly connect to the tandem; or 2) connect to the nearest standalone or host wire center that is on a ring. The option that yields the shortest spur distance is selected. In either case, redundant facilities are provided.

At the highest level in the ring network, the HM must provide a path for tandem to tandem traffic for tandems that are located in the same LATA. This is accomplished through the use of inter-ring-system connectors.[65] The inter-ring-system connectors facilitate a fully interconnected mesh of all the ring systems that exist within a LATA. Ring systems may be connected to other ring systems either through direct tandem to tandem paths, or through any of the on-ring nodes served by those tandems. Inter-ring-system connectors always follow route-diverse paths and will, in most cases, terminate at unique nodes within each of the ring systems. The nodes and paths selected are those that produce the shortest two paths between ring systems. . To ensure tandem switches are sized to handle inter-tandem traffic, there is a user-adjustable parameter (default value 0.10), identified in Appendix B as "Intertandem Fraction of Tandem Trunks," and expressed as a multiplier of the number of tandem trunks calculated from traffic volumes, that increases the calculated capacity of the tandem switches.

The result of the ring-calculating process is a list of the computed host/remote and tandem/host/standalone ring configurations. These ring configurations are broken out by each tandem or host, and the wire centers they serve through the ring network. The following information is reported in the workfile "ring_io" worksheet for each set of rings: 1) the set of wire centers that comprise the ring; 2) the identification of each wire center and the nodes (other wire centers) to which it connects; 3) the distance between each wire center and the nodes to which it connects; 4) a list of the wire centers served by spurs and their associated spur distance; 5) a list of the wire centers that serve as inter-ring-system connector nodes and their associated inter-ring-system connector distance; and 6) a list of the wire center pairs that serve as ring connectors and the their associated ring connector distances. In addition to the ring distance associated with each wire center, several ring parameters are aggregated by company. These include: 1) the total number of ring connectors; 2) the total ring connector distance; 3) the total number of inter-ring-system connectors; 4) the total inter-ring-system connector distance; and 5) the total number of rings that include the tandem as a node. The model equips each ring connector with the maximum rate SONET equipment (OC-48) in current common use by the LECs. Spur terminals operate at OC-3, a sufficient capacity given the 5000 line threshold for the smaller wire centers being placed on a spur.

Once the model determines the total interoffice distances, considering rings, connectors, and point-to-point links for small offices, it calculates the costs of installed cable and structure based on user-definable inputs for cable costs, structure costs and configurations (e.g., pullbox spacing), the mix of different structure types, and the amount of structure sharing between interoffice and feeder plant. To account for this structure sharing, the model determines the smaller of the investment in feeder and the investment in

[65] A ring system is defined as the set of nodes, connectors, spurs, and ring connectors associated with a particular tandem.

interoffice facilities, and applies the user-specified sharing percentage to the smaller value to calculate the amount of shared structure investment. The model then subtracts this amount of investment from both the interoffice and feeder investment, and reassigns it back to feeder and interoffice according to the relative amounts of investment in feeder versus interoffice. It does this separately for underground, buried, and aerial structure.

Interexchange access facilities require additional treatment. Because interexchange carrier POPs are typically not located on LEC fiber rings, dedicated entrance facilities must be engineered. It is not possible to compute the route miles between wire centers (or tandems) and IXC POPs to size the lengths of these entrance facilities, because in general the locations of IXC POPs are not publicly available. Therefore, the number of POPs per tandem, and the average entrance facility distance, are user-adjustable, with default values of 5 and 0.5 miles, respectively.

6.5.3.3. Tandem Switch Investments

Tandem and operator tandem switching investments are computed according to assumptions contained in an AT&T cost study.[66] The investment calculation assigns a price for switch "common equipment," switching matrix and control structure, and adds to these amounts the investment in trunk interfaces. The numbers of trunks and their related investments, are derived from the transport calculations described above.

The module scales the investment in tandem switch common equipment according to the total number of tandem trunks computed for the study area. By doing so, it avoids equipping maximum-capacity tandems whenever a LATA is served by multiple tandems. The calculations also recognize that a significant fraction of tandems are "Class 4/5" offices that serve both tandem and end office functions. The amount of sharing assumed is user-adjustable, with a default value of 40%. Tandem wire center calculations assume the maximum switch room size, and further assume the tandem will reside in a wire center that contains at least one end office switch.

6.5.3.4. Signaling Network Investments

The Module computes signaling link investment for STP to end office to or tandem "A links," "C links" between the STPs in a mated pair, and "D link" segments connecting the STPs of different carrier's networks. All links are assumed to be carried on the interoffice rings.

The model always equips at least two signaling links per switch. It also computes required SS7 message traffic according to the call type and traffic assumptions described earlier. User inputs define the number and length of ISDN User Part ("ISUP") messages

[66] AT&T, "An Updated Study of AT&T's Competitors' Capacity to Absorb Rapid Demand Growth," filed with the FCC in CC Docket No. 79-252, April 24, 1995, and its predecessor, "A Study of AT&T's Competitors' Capacity to Absorb Rapid Demand Growth," June 20, 1990. ("AT&T Capacity Cost Study").

required to set up interoffice calls. Default values are six messages per interoffice call attempt to set up, with twenty-five octets per message.

Other inputs define the number and length of Transaction Capabilities Application Part ("TCAP") messages required for database lookups, along with the percentage of calls requiring TCAP message generation. Default values, obtained from the AT&T Capacity Cost Study, are two messages per transaction, at 100 octets per message, and 10% of all calls requiring TCAP generation. If the message traffic from a given switch exceeds the link capacity (also user-adjustable and set at 56 kbps and 40% occupancy as default values), the model will add links to carry the computed message load. The total link distance calculation includes all the links required by a given switch.

STP capacity is expressed as the total number of signaling links each STP in a mated pair can terminate (default value is 720 with an 80% fill factor). The maximum investment per STP pair is set at $5 million, and may be changed by the user. These default values derive from the AT&T Capacity Cost Study. The STP calculation scales this investment based on the number of links the model requires to be engineered for the study area.

SCP investment is expressed in terms of dollars of investment per transaction per second. The transaction calculation is based on the fraction of calls requiring TCAP message generation. The total TCAP message rate in each LATA is then used to determine the total SCP investment. The default SCP investment is $20,000 per transaction per second, based on a number reported in the AT&T Capacity Cost Study.

6.5.3.5. Operator Systems Investments

Operator tandem and trunk requirements are based on the operator traffic fraction inserted by the user into the model and on the overall maximum trunk occupancy value of 27.5 CCS discussed above. Operator tandem investment assumptions are the same as for local tandems.

Operator positions are assumed to be based on current workstation technology. The default operator position investment is $6,400. The Model includes assumptions for maximum operator "occupancy" expressed in CCS. The default assumption is that each position supports 32 CCS of traffic in the busy hour. Also, because many operator services traditionally handled by human operators may now be served by announcement sets and voice response systems, the model includes a "human intervention" factor that reflects the fraction of calls that require human operator assistance. The default factor is 10, which is believed to be a conservative estimate. (A factor of 10 implies that one out of ten calls will require human intervention).

6.6. Expense Modules

6.6.1. Overview

HM 5.0a contains four Expense Modules in order to allow the user to display results by line density range, by wire center, by CBG or by cluster.[67] Each of the Expense Modules receive from the other modules all the network investments, by type of network component necessary to provide UNEs, basic universal service and network interconnection and carrier access in each study area. The Expense Modules estimate the capital carrying costs associated with the investments as well as the costs of operating this network. Capital carrying costs include depreciation, return on the debt and equity investment required to build the network and a gross-up to pay for the income taxes imposed on equity returns. Network-related operating expenses include maintenance and network operations. Non-network-related operating expenses include customer operations expenses, general support expenses, other taxes, uncollectibles and variable overhead expenses.

The Expense modules require a number of user inputs. These inputs, and their corresponding default values, appear as inputs B178-B196 in Appendix B.

[67] Although the HM 5.0a engineers no plant based on CBG granularity, the results of its engineering to individual clusters may be rolled up to display cost results at the CBG level.

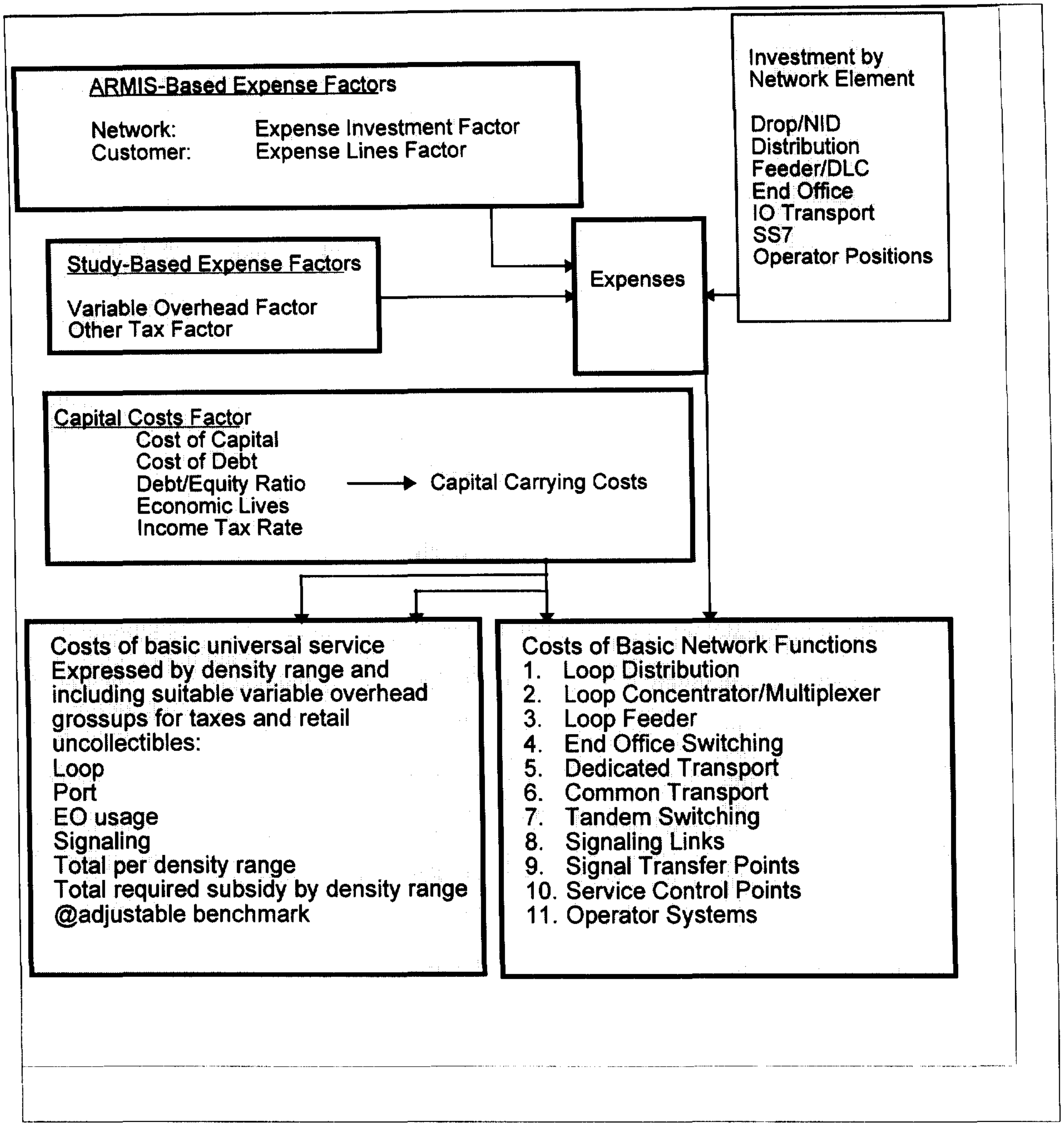

Figure 10 Expense Module Flows

6.6.2. Capital Carrying Costs

Estimating forward-looking capital carrying costs is relatively straight-forward. The FCC and state regulators have developed standard practices that are based on sound economics to perform this function. The model calculates annual capital cost for each UNE component based on:

a) Plant investment for that component from the relevant investment modules,

b) The return to the net asset;

c) An income tax gross-up on the equity component of the return, and

d) The expected service life adjusted for net salvage value (depreciation) of the component.

Each of these elements of the capital carrying cost estimate is discussed below.

The weighted average cost of capital (return) is built up from several components. A 45/55 debt/equity ratio is assumed, with a cost of debt of 7.7 percent and a cost of equity of 11.9 percent, for an overall weighted average cost of capital of 10.01 percent.[68] The equity component of the return is subject to federal, state and local income tax. As a consequence, it is necessary to increase the pre-tax return dollars, so that the after-tax return is equal to the assumed cost of capital. A user-adjustable assumed combined 39.25 percent federal, state and local income tax ("FSLIT") rate is used "gross up" return dollars to achieve this result.

The model assumes straight-line depreciation and calculates return on investment, tax gross-up and depreciation expenses annually on the mid-year value of the investment. Because capital carrying costs are levelized, substitution of nonlinear or accelerated depreciation schedules for straight-line depreciation would have only a modest net effect on calculated annual capital carrying costs (aside from favorable tax effects). Default values for the service lives of the 23 categories of equipment used in the Model are based on their average projection lives adjusted for net salvage value as determined by the three-way meetings (FCC, State Commission, LEC) for 76 LEC study areas including all of the RBOCs, SNET, Cincinnati Bell, and numerous GTE and United companies. The table below shows the plant categories, their economic lives, their percent net salvage value, and the resulting adjusted projection lives upon which depreciation is based. These economic lives and net salvage percents are user-adjustable.

[68] This assumed cost of capital is conservatively high. Current financial analyses show LEC cost of capital to range between 9 and 10 percent. See, AT&T ex parte filing of February 12, 1997, "Estimating the Cost of Capital of Local Telephone Companies for the Provision of Network Elements," by Bradford Cornell, September, 1996.

Account	USOA Category	Economic Lives	Net Salvage Percent	Adjusted Projection Lives
2112	Motor Vehicles	8.24	0.1121	9.28
2115	Garage Work Equipment	12.22	-0.1071	11.04
2116	Other Work Equipment	13.04	0.0321	13.47
2121	Buildings	46.93	0.0187	47.82
2122	Furniture	15.92	0.0688	17.10
2123.1	Office Support Equipment	10.78	0.0691	11.58
2123.2	Company Comm Equipment	7.40	0.0376	7.69
2124	Computers	6.12	0.0373	6.36
2212	Digital Switching	16.17	0.0297	16.66
2220	Operator Systems	9.41	-0.0082	9.33
2232.2	Digital Circuit Equipment	10.24	-0.0169	10.07
2351	Public Telephone	7.60	0.0797	8.26
	NID, SAI			19.29
2411	Poles	30.25	-0.8998	15.92
2421-m	Aerial Cable - Metallic	20.61	-0.2303	16.75
2421-nm	Aerial Cable - Non-Metallic	26.14	-0.1753	22.24
2422-m	Underground - Metallic	25.00	-0.1826	21.14
2422-nm	Underground - Non-Metallic	26.45	-0.1458	23.08
2423-m	Buried - Metallic	21.57	-0.0839	19.90
2423-nm	Buried - Non-Metallic	25.91	-0.0858	23.86
2426-m	Intrabuilding - Metallic	18.18	-0.1574	15.71
2426-nm	Intrabuilding - Non-Metallic	26.11	-0.1052	23.62
2441	Conduit Systems	56.19	-0.1034	50.92
	Average Metallic Cable (calculated)			19.29

Return is earned only on net capital, but because depreciation results in a declining value of plant in each year, the return amount declines over the service life of the plant. To ensure that a meaningful long run capital carrying cost is calculated, the return amount is levelized over the assumed life of the investment using net present value factors. An annual capital carrying charge factor is developed for economic depreciation lives from 1 to 80 years. (*see*, "CCCFactor" worksheet in the Expense Module). These factors (which are also disaggregated into their depreciation, return and tax components) are then applied to investment in each plant category (with interpolation to account for fractional year values for economic life) to determine the annual capital carrying cost for each plant category.

6.6.3. Operating Expenses

Estimating LEC operating costs is more difficult than estimating capital costs. Few publicly available forward-looking cost studies are available from the ILECs. Consequently, many of the operating cost estimates developed here must rely on relationships to and within historical ILEC cost information as a point of departure for estimating forward-looking operating costs. While certain of these costs are closely linked to the number of lines provided by the ILEC, other categories of operating expenses are related more closely to the levels of their related investments. For this reason, the Expense Module develops factors for numerous expense categories and applies these factors both against investment levels and demand quantities (as appropriate) generated by previous modules.

The HM 5.0a density zone Expense Module now includes a USOA Detail worksheet that breaks out the HM 5.0a investments and expense results by Part 32 account for comparison with embedded ARMIS data. There is also an Expense Assignment worksheet that allows the user to vary the proportion of total expenses that are assigned to loop network elements (i.e., NID, distribution, concentration and feeder) based on relative number of lines versus based on the relative amount of direct expenses (direct expenses include maintenance expenses and capital carrying costs for specific network elements).

The operating expenses can be divided into two categories -- network related and non-network related. Network-related expenses include the cost of operating and maintaining the network, while non-network expenses include customer operations and variable overhead.

The cost categories contained in the FCC's USOA are used as the point of departure for estimating the operating expenses associated with providing UNEs, basic universal service and carrier access and interconnection. The major expense categories in the USOA are Plant Specific Operations Expense, Plant Non-Specific Operations Expense, Customer Operations Expense and Corporate Operations Expense. The first two are network-related, the latter are not.

LECs report historical expense information for each of these major categories through the FCC's ARMIS program. The ARMIS data used in the Expense Module include investment and operating expenses and revenues for a given local carrier and state. As noted above, forward-looking expense information for these categories is not publicly available from the ILECs. A variety of approaches are used to estimate the forward-looking expenses.

6.6.3.1. Network-Related Expenses

The two major categories under which network-related expenses are reported by the ILECs are plant-specific operations expenses and non plant-specific operations expenses. The plant-specific expenses are primarily maintenance expenses. Certain expenses, particularly those for network maintenance, are functions of their associated capital investments. The Expense Module estimates these from historic expense ratios calculated from balance sheet and expense account information reported in each carrier's ARMIS report. These expense ratios are applied to the investments developed by the Distribution, Feeder, and Switching and Interoffice Modules to derive associated operating expense amounts. The ARMIS information used to perform these functions is contained in the "ARMIS Inputs" worksheet, and the expense factors are computed in the "'96 Actuals" worksheet of the Expense Module.

Other expenses, such as network operations, vary more directly with the number of lines provisioned by the ILEC rather than its capital investment. Thus, expenses for these elements are calculated in proportion to the number of access lines supported.

The Expense Module estimates direct network-related expenses for all of the UNEs. These operating expenses are added to the annual capital carrying cost to determine the total expenses associated with each UNE. Each network-related expense is described below:

a) *Network Support* -- This category includes the expenses associated with motor vehicles, aircraft, special purpose vehicles, garage and other work equipment.

b) *Central Office Switching* -- This includes end office and tandem switching as well as equipment expenses.

c) *Central Office Transmission* -- This includes circuit equipment expenses applied to transport investment.

d) *Cable and Wire* -- This category includes expenses associated with poles, aerial cable, underground/buried cable and conduit systems. This expense varies directly with capital investment.

e) *Network Operations* -- The Network Operations category includes power, provisioning, engineering and network administration expenses.

The Expense Module uses specific forward-looking expense factors for digital switching and for central office transmission equipment; these values derive from a New England Telephone cost study.[69] The Module similarly computes a forward-looking Network Operations value based on the corresponding ARMIS value. The total Network Operations expense is strongly line-dependent. The model thus computes this expense as a per-line additive value based on the reported total Network Operations expense divided by the number of access lines and deducting a user-adjustable 50 percent of the resulting quotient to produce a forward-looking estimate.

6.6.3.2. NonNetwork-Related Expenses

The Expense Module assigns non-network related expenses to each density range, census block group, or wire center (depending on the unit of analysis chosen) based on the proportion of direct expenses (network expenses and capital carrying costs) for that unit of analysis to total expenses in each category. Each of these expenses is described below:

[69] New England Telephone, 1993 New Hampshire Incremental Cost Study, Provided in Compliance with New Hampshire Public Utility Commission Order Number 20, 082, Docket 89-010/85-185, March 11, 1991.

a) *Variable support* -- Certain costs that vary with the size of the firm, and therefore do not meet the economic definition of a pure overhead, are often included under the classification of General and Administrative expenses by ILECs. For example, if a LEC did not provide loops, it would be a much smaller company, and would therefore have lower overhead costs. Some of these costs are nonetheless attributed to overhead under current ILEC accounting procedures. Therefore, the model includes a portion of these "overhead" costs in the TSLRIC estimates.

Such variable support expenses for LECs currently are substantially higher than those of similar service industries operating in more competitive environments. Based on studies of these variable support expenses in competitive industries such as the interexchange industry, the model applies a conservative, user-adjustable 10.4 percent variable support factor to the total costs (i.e., capital costs, network-related operations expenses and non-network-related operating expenses) estimated for unbundled network elements, as well as basic local service.

b) *General Support Equipment* -- The module calculates investments for furniture, office equipment, general purpose computers, buildings, motor vehicles, garage work equipment, and other work equipment. The Model uses actual 1996 company investments to determine the ratio of investments in the above categories to total investment. The ratio is then multiplied by the network investment estimated by the Model to produce the investment in general support equipment. The recurring costs -- capital carrying costs and operating expenses -- of these items are then calculated from the investments in the same fashion as the recurring costs for other network components. A portion of general support costs is assigned to customer operations and corporate operations according to the proportion of operating expense in these categories to total operating expense reported in the ARMIS data. The remainder of costs is then assigned directly to UNEs.

c) *Uncollectible Revenues* -- Revenues are used to calculate the uncollectibles factor. This factor is a ratio of uncollectibles expense to adjusted net revenue. The Module computes both retail and wholesale uncollectibles factors, with the retail factor applied to basic local telephone service monthly costs and the wholesale factor used in the calculation of UNE costs.

6.6.4. Expense Module Output

The Density Zone and Wire Center expense modules display results in a series of reports which depict detailed investments and expenses for each UNE for each density zone and wire center, summarized investments and expenses for all UNEs, unit costs by UNE and total annual and monthly network costs. In addition, the UNEs are used to estimate interexchange access costs. The Density Zone, Wire Center, CBG and Cluster expense modules also calculate the cost of basic local service and universal service support across density zones, wire centers, CBGs and clusters, respectively.

6.6.4.1. UNE Outputs (Unit Cost Sheet)

The HAI Model produces cost estimates for Unbundled Network Elements that are the building blocks for all network services. The UNEs are described below.

a) *Network Interface Device* -- This is the equipment used to terminate a line at a subscriber's premise. It contains connector blocks and over-voltage protection.

b) *Loop Distribution* -- The individual communications channel to the customer premises originating at the SAI and terminating at the customer's premises. In the HAI Model, this UNE also includes the investments in NID, drop and terminal/splice, and for long loops, the cost of T1 electronics.

c) *Loop Concentrator/Multiplexer* -- The DLC remote terminal at which individual subscriber traffic is multiplexed and connected to loop distribution for termination at the customer's premises. The HAI Model includes DLC equipment and SAI investment in this UNE.

d) *Loop Feeder* -- The facilities on which subscriber traffic is carried from the line side of the end office switch to the Loop Concentration facility. The UNE includes copper feeder and fiber feeder cable, plus associated structure investments (poles, conduit, etc.)

e) *End Office Switching* -- The facility connecting lines to lines or lines to trunks. The end office represents the first point of switching. As modeled in the HAI Model, this UNE includes the end office switching machine investments and associated wire center costs, including distributing frames, power and land and building investments.

f) *Operator Systems* -- The systems that process and record special toll calls, public telephone toll calls and other types of calls requiring operator assistance, as well as Directory Assistance. The investments identified in the HAI Model for the Operator Systems UNE include the operator position equipment, operator tandem (including required subscriber databases), wire center and operator trunks.

g) *Common Transport* -- A switched trunk between two switching systems on which traffic is commingled to include LEC traffic as well as traffic to and from multiple IXCs. These trunks connect end offices to tandem switches. Results are provided on a per-minute basis for the central office terminating equipment associated with the UNE, and for the transmission medium.

h) *Dedicated Transport* -- The full-period, bandwidth-specific interoffice transmission path between LEC wire centers and an IXC POP (or other off-network location). It provides the ability to send individual and/or multiplexed switched and special services circuits between switches. Results are provided on a per-minute basis and per-channel basis for the central office terminating equipment and entrance facilities associated with the UNE, and on a per-minute and per-channel basis for the transmission medium.

i) *Direct Transport* -- A switched trunk between two LEC end offices. Results are provided on a per-minute basis for the central office terminating equipment associated with the UNE, and on a per-minute basis for the transmission medium.

j) *Tandem Switching* -- The facility that provides the function of connecting trunks to trunks for the purpose of completing inter-switch calls. Similar types of investments as are included in the End Office Switching UNE are also reflected in the Tandem Switching UNE.

k) *Signaling Links* -- Transmission facilities in a signaling network that carry all out-of-band signaling traffic between end office and tandem switches and STPs, between STPs, and between STPs and SCPs. Signaling link investment is developed by the HAI Model and assigned to this UNE.

l) *Signal Transfer Point* -- This facility provides the function of routing TCAP and ISUP messages between network nodes (end offices, tandems and SCPs). The Model estimates STP investment and assigns it to this UNE.

m) *Service Control Point* -- The node in the signaling network to which requests for service handling information (*e.g.*, translations for local number portability) are directed and processed. The SCP contains service logic and customer specific information required to process individual requests. Estimated SCP investment is assigned to this UNE.

6.6.4.2. Universal Service Fund Outputs (USF Sheet)

The calculation of costs for basic local service is based on the costs of the UNEs constituting this service. These are the loop, switch line port, local minute portions of end office and tandem switching, transport facilities for local traffic, and the local portions of signaling costs.[70] In addition, costs associated with retail uncollectibles, variable overheads, and certain other expenses required for basic local service, such as billing and bill inquiry, directory listings, and number portability costs, are included. No operator services or SCP costs are included. The model user has the ability to select dynamically the portions of non-traffic-sensitive UNEs to be included in the supported basic local service.

The USF report in the expense module then compares the monthly cost per line used at residence or business intensity in each density range, wire center, CBG or cluster to user-adjustable "benchmark" monthly costs for local service (which includes the End User Common Line charge). If the cost exceeds the associated benchmark, the model accumulates the total required annual support relative to stated benchmarks according to the number of primary residence lines, secondary residence lines, single line business lines, multiline business lines, or public lines by density zone, wire center, CBG or cluster (depending on the unit of analysis selected).

[70] On an optional basis, the usage sensitive cost of switched access use can be included as well.

The Density Zone USF sheet now contains separate state and federal fund calculations. These permit separate state and federal cost benchmarks; as well as the opportunity to separately specify the particular services (e.g., primary and secondary residential lines, single line business, etc.) to be supported.

6.6.4.3. Carrier Access and Interconnection (Cost Detail Sheet)

The calculation of the costs for carrier access and interconnection to the ILEC's local network are displayed in the "Cost Detail" sheet of the expense module. These costs are built up from the costs of the UNEs that constitute them. In particular, the costs of IXC switched access and local interconnection are based simply on the unit costs of EO switching, dedicated transport, common transport, tandem switching and ISUP signaling messages. In addition, the sheet also displays built up costs of various signaling services that might be used by IXCs or CLECs, as well as the costs of several forms of dedicated transport.

7. Summary

In its Release 5.0a formulation, the HAI Model reliably and consistently estimates the forward-looking economic cost of unbundled local exchange network elements, carrier access and interconnection and the forward-looking economic cost of basic local telephone service for universal service funding purposes. It uses the most accurate and granular data on actual customer locations available today, and it overlays its loop distribution network on these actual customer locations.

Because all of these calculations are performed in adherence to TELRIC/TSLRIC principles, HAI Model cost estimates provide the most accurate basis for the efficient pricing of unbundled network elements carrier access and interconnection and the calculation of efficient universal service funding requirements.

Like its predecessor, the HM 5.0a methodology is open to public scrutiny. To the extent possible, it uses public source data for its inputs. When documentable public source data is lacking, these default input values represent the developers' best judgments of efficient, forward-looking engineering and economic practices. In addition, because these inputs are adjustable users of HM 5.0a can use the model's automated interface to model directly and simply any desired alternative.